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(54) METHOD FOR DETERMINING OCCUPANT POSITION TO ADAPT A RESTRAINT DEPLOYMENT OF A VEHICLE AND SYSTEM FOR DETERMINING AN OCCUPANT POSITION IN A VEHICLE TO BE USED IN A RESTRAINT DEPLOYMENT ADAPTION IN A VEHICLE

(57) In a method and a system for determining positions of an occupant in a vehicle to adapt a restraint deployment of the vehicle (1), at least one 3D sensor system (21) is applied to capture a plurality of time-delayed image frames of the at least one occupant (3) in the vehicle (1). A Kalman filter (40) determines a filtered head position (33F), a filtered right shoulder position (34F), a filtered left shoulder position (35F), and a filtered middle spine position (37F) from the plurality of body points (32) and predicts state (st) evolution in case of occlusion or transitory low measurement quality. A calculation section (50) calculates a current 3D head position (33) and a current 3D chest position (36) which are used for the adaption of the restraint deployment of vehicle (1).

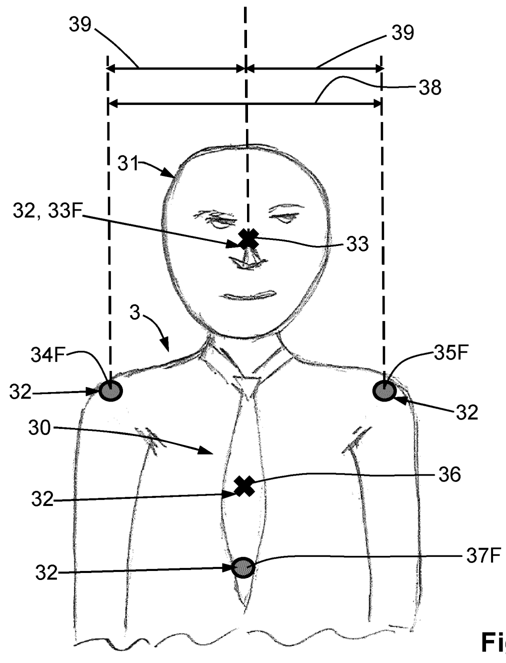

Fig. 4

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Description

FIELD OF THE INVENTION

[0001] The invention relates to a method for determining at least one position of an occupant in a vehicle to adapt a restraint deployment development of the vehicle.

[0002] The invention further relates to a system for determining positions of an occupant in a vehicle to be used in a restraint deployment adaption of a vehicle. The system comprises an electronic control unit being part of the vehicle. The electronic control system encompasses at least a fusion module, an event detection module, an occupant displacement prediction module, and a deployment requests module. At least one 3D sensor system is adapted to capture a plurality of time-delayed image frames of the at least one occupant in the vehicle, and the at least one 3D sensor system is linked to a signal acquisition and processing module of a crash algorithm.

DESCRIPTION OF THE BACKGROUND ART

[0003] US 2004/0153229 A1 relates to sensor system for determining a deployment level of an airbag in a vehicle. A light source of the sensor system emits light onto a region around a vehicle seat. An array of light-sensitive pixels which capture reflected light from the scene, including reflected light that originated from the light source. Processing resources are provided that determine depth information for an object in the scene based on a time-of-flight characteristic of the reflected light from the light source captured on the array. The processing resources may be configured to determine occupancy data for the object based on the captured reflected light from the scene. The processing resources are configured to determine the deployment level of the airbag based at least in part on the occupancy data in when a collision of the vehicle occurs.

[0004] US-Patent US 5 653 462 A discloses an occupant position sensor utilizing either ultrasonic, microwave or optical technologies, or seatbelt spool out and seat position sensors, are used as inputs to the primary vehicle crash sensor circuit to permit the longest possible sensing time before the occupant gets proximate to the airbag and is in danger of being injured by the deploying airbag. The sensor further disables the inflatable restraint system if the occupant is in danger of being injured by the system deployment. Separate systems are used for the driver and passenger to permit the optimum decision to be made for each occupant.

[0005] US-Patent US 5 531 472 discloses an apparatus for controlling an occupant restraint system in a vehicle. A ROM memory is provided for storing a block of image data representative of a viewing field within the vehicle. The viewing field includes an unoccupied vehicle seat located in the occupant compartment of the vehicle. A new block of image data is obtained which is representative of the viewing field with an occupant on the seat. This image data is obtained with an image sensor, such as a CCD sensor, mounted in the vehicle for viewing the field. The new block of image data is compared with the stored block of image data by a controller to obtain the occupant's size and/or position in the vehicle. The provides a control signal having a value which is a function of the comparison. A restraint regulator, such as a vent valve, responds to the control signal for controlling the occupant restraint system.

[0006] Current algorithms make an indirect estimate of the occupant size and occupant position based on the seat track and/or seat weight sensors to classify occupants (small or large). The restraint deployment strategies are calculated and optimized for certain types of occupants in specific positions.

SUMMARY OF THE INVENTION

[0007] It is an object of the present invention to provide a method for providing exact data on the size and position of an occupant in a vehicle so that the deployment of the restraint system can be adapted smartly and to prevent the risk of injury to the occupant from the deploying airbag.

[0008] The above object is achieved by a method for determining occupant position to be used in a restraint deployment adaption in a vehicle according to the features of claim 1.

[0009] It is a further object of the present invention is to provide a system for determining positions of an occupant used in a restraint deployment adaption in a vehicle so that the deployment of the restraint system can be adapted smartly and to prevent the danger of injury to the occupant from the deploying airbag.

[0010] The above object is achieved by a system for determining positions of an occupant used in a restraint deployment adaption in a vehicle according to the features of claim 11.

[0011] In an embodiment of the method, at least one 3D sensor system is used to capture a plurality of time-delayed image frames of the at least one occupant in the vehicle. A 3D position for each of a plurality of body points is determined from raw image data per captured image frame of the occupant. The 3D positions of the plurality of body points are transmitted to a Kalman filter to determine a filtered head position, a filtered right shoulder position, a filtered left shoulder position, and a filtered middle spine position from the plurality of body points. The filtered head position, the filtered right shoulder position, the filtered left shoulder position and the filtered middle spine position are input to a calculation section which calculates a current 3D head position and a current 3D chest position of the occupant. The current 3D head position and the current 3D chest position are used as an input for the determination of the occupant's position in the vehicle and an adaption of the restraint deployment of the vehicle. The calculation of the current 3D head position and the current 3D chest position is based on 3D image sensing of the position of the occupant and uses 3D body points which are a set of x, y and z point locations on the body surface of the occupant.

[0012] The advantage of the present invention is that a determined chest and head position of the occupant, even if points to be measured, regarding the points on the body surface, are occluded manage the time of the deployment of an airbag or even determine whether or not an inhibition of the airbag is needed.

[0013] In an embodiment, a signal processing module is applied to calculate a state ***st*** for each image frame of the plurality of body points of the occupant. Each body point is defined by its position in an x-direction, a y-direction and a z-direction and its corresponding speed in the x-direction, in the y-direction, and in the z-direction.

[0014] In addition, the exact chest and head position can be determined even if there is noise or one body point is occluded for a certain time.

[0015] To adapt restraint deployment in function of occupant size and position and to ensure the occupant safety in the vehicle, an exact calculation of the size and position of the occupant is required. Here, the occupant position, defined by the exact chest and head position is required.

[0016] An enhanced usage of the Kalman filter may comprise various steps to calculate the filtered head position, the filtered right shoulder position, the filtered left shoulder position, and the filtered middle spine position. One step may be predicting a state of a 3D position for each of a plurality of body points of the occupant by taking the previous 3D position for each of a plurality of body points of the occupant and an error estimate. Another step may be a correcting step which compares the predicted position for each of a plurality of body points of the occupant and the measured 3D position for each of a plurality of body points of the occupant. A further step may be an updating step of the 3D position for each of a plurality of body points of the occupant for one image frame with the measured 3D position of a plurality of body points of the occupant. Even when a 3D body point is occluded (for example with a bag, map or the like) it is always possible that the body point position is estimated.

[0017] Without using this enhanced way of the Kalman filter, the detection of these body points (left shoulder point, right shoulder point, head point, middle spine point, etc.) could be affected by sensor noise and/or failure. In this case, the visual feature measurements cannot be extracted or provide erroneous values. Raw measurements directly affect the calculation of the occupant position so that optimal airbag deployment is not ensured.

[0018] The input data can sometimes be noisy, disturbed and inaccurate, either related to the sensor or related to a specific situation (occlusion or image noise). One possible disturbance of a 3D point occlusion is that a large bag is placed on the occupant's lap and may occlude the chest position. Another possible disturbance of a 3D point occlusion is that the passenger or occupant reads a magazine or a book that may occlude the head position. Further, a passenger or occupant takes a large sheet map that may cover or occlude the chest and the head position.

[0019] A 3D sensor failure may be caused when the occupant smokes and due to cigarette or vape smoke, the 3D sensor system or 3D sensor could not extract the correct 3D body points. Another 3D sensor failure is caused by light interference with the camera, phone light, reflection from a watch or glasses. A sudden change in light from very dark to bright, which occurs, for example, when the vehicle is driving through a tunnel.

[0020] These multiple situations can directly impact the occupant safety when airbag deployment is based on the occupant position calculated from the 3D key body points that might be erroneously detected.

[0021] To overcome this sensor and/or body point extraction problem, the Kalman filter is used, which can remove sensor noise and predict data when the measurements are occluded, as described above.

[0022] In an embodiment, the Kalman filter is used not only for filtering but also for predicting body points when any of the body points cannot be extracted by the sensor due to a sensor failure or due to a certain situation obscuring the body point. The predicting step of the Kalman filter may predict the state according to the system model for the next iteration. The filter uses the dynamics of each 3D body point, which defines its evolution over time, to obtain better data and thus eliminate the effect of noise.

[0023] In an embodiment, the enhanced method of the Kalman filter includes, before the correction step, an eligibility test to determine whether the measured 3D position and the model are valid. The eligibility test can be based on the Mahalanobis distance based on measurement error estimation or other measure quality estimations. A measurement error may be the difference the between the raw image data and the predicted 3D positions of the body points. The threshold chosen can ensure that the observations and/or measurements and the prediction are within an acceptance range. Given the Gaussian properties, this acceptance range may be an ellipsoid with center $\hat{z}$ and matrix $\boldsymbol{S}$. This threshold may also discriminate or eliminate the measurement jumps related to voluntary or involuntary dynamic movements of the occupant.

[0024] Once the key body points are filtered, the head position corresponds to the filtered head point or is predicted if the head point was occluded. A coherence check may be carried out, using the filtered head position, the filtered right shoulder position, and the filtered middle spine position. This is a check to determine whether or not the position of one 3D point in relation to other body points respects the morphology of the person. This is to check, for example, the width between the body point of the left shoulder and the body point of the right shoulder, or the distance between the head between the body point of the left shoulder and the body point of the right shoulder. The coherence check is carried out on the filtered head position, the filtered right shoulder position, the filtered left shoulder position, and the filtered middle spine position to determine the 3D head position. A result of the coherence check may be sent to a point combination to determine the 3D chest position.

[0025] This coherence check could be also used to determine whether or not the occupant is in an out-of-range position in the seat. For example, if the driver turns backwards to see the rear seats while driving with this coherence check, a warning could be added to alert the driver that he is in an out-of-range position.

[0026] In an embodiment, a non-transitory computer-readable medium stores program instructions executable on an electronic control unit of a vehicle to perform a computer-implemented method for determining a 3D head position and a 3D chest position of an occupant in a vehicle. The outputs of the 3D head position and the 3D chest position may be used as inputs of a function that defines the occupant position in a vehicle to adapt a restraint deployment development of a vehicle.

[0027] The occupant position could not solely rely on the position of the seat, in real life the occupant could have different positions on the seat. For this reason, it is important for restraint deployment to have an accurate determination of the occupant's 3D chest position and 3D head position from the dashboard. These distances could control the time of the deployment or even determine whether or not an inhibition of the airbag is required.

[0028] The safety devices are airbags, adaptive airbags, seat belts, belt tensioners, seat belt pretension or the like. The 3D sensor system comprises at least one 3D imaging sensor. The 3D sensor system can be configured as well as an interior time-of-flight camera, a 3D camera system, or an interior radar system, or any combination of the latter.

[0029] An embodiment of the system for determining positions of an occupant used in a restraint deployment adaption in a vehicle comprises an electronic control unit of the vehicle. A fusion module, an event detection module, an occupant displacement prediction module, and a deployment requests module are part of the electronic control system. At least one 3D sensor system is adapted to capture a plurality of time-delayed image frames of the at least one occupant in the vehicle, the at least one 3D sensor system being connected to a signal acquisition and processing module of a crash algorithm. A Kalman filter is implemented in the signal processing module and determines a filtered head position, a filtered right shoulder position, a filtered left shoulder position and a filtered middle spine position from a plurality of body points captured by the at least one 3D sensor system. A calculation section is provided which calculates a current 3D head position and a current 3D chest position from the filtered head position, the filtered right shoulder position, the filtered left shoulder position, and the filtered middle spine position. The current 3D head position and the current 3D chest position are used in the crash algorithm.

Definitions:

Kalman Filter

[0030] A Kalman filter can be applied wherever one has an uncertain information about a dynamic system (occupant in a vehicle) and one can make an educated guess as to what the system will do next. Even if a chaotic reality shows up and interferes with the clean motion one guessed about, the Kalman filter will often do a very good job of figuring out what actually happened, and it can take advantage of correlations between absurd phenomena that one might not have thought to exploit.

[0031] Kalman filters are ideal for systems which are continuously changing. They have the advantage of being small in memory (since they do not need to keep any history other than the previous state), and they are very fast, making them well-suited for real-time problems and embedded systems.

Mahalanobis Distance

[0032] The Mahalanobis distance is an effective multivariate distance metric that measures the distance between a point and a distribution. It is an extremely useful metric with excellent applications in multivariate anomaly detection, classification on highly imbalanced datasets, and one-class classification. A combination of the Mahalanobis distance with independent quality measure estimation is used to see if the measurement is valid or not. This combination is different from a standard Kalman filter implementation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The numerous advantages of the disclosure may be better understood by those skilled in the art by reference to the accompanying figures in which:

Figure 1 is a schematic view illustrating a vehicle including an ECU for controlling various protection devices.

Figure 2 is a schematic representation of a 3D sensor system for determining the current position of an occupant in a vehicle.

Figures 3A to 3C are different schematic views showing the relationship between the head or chest distance from the steering wheel or the dashboard.

Figure 4 is a schematic representation of a plurality of 3D body points on an occupant's body, which are used for the calculation or determination of the current head position and chest position of the occupant.

Figure 5 is a schematic representation of the steps for determining the 3D head and chest position of the occupant in the vehicle.

Figure 6 is a schematic view of the filter steps used in the Kalman filter to determine the 3D head and the chest position of the occupant in the vehicle.

Figure 7 is a schematic view of an embodiment of the crash algorithm using the occupant size, the occupant chest distance and the occupant head distance to the steering wheel and/or dashboard.

DETAILED DESCRIPTION

[0034] In the ensuing description, numerous specific details are provided to enable maximum understanding of the embodiments that are provided by way of example. The embodiments may be implemented with or without specific details, or else with other methods, components, materials, etc. In other circumstances, well-known structures, materials, or operations are not illustrated or described in detail so that various aspects of the embodiments will not be obscured. Reference in the course of the present description to "an embodiment" or "one embodiment" means that a particular structure, peculiarity, or characteristic described in connection with its implementation is comprised in at least one embodiment. Hence, phrases such as "in an embodiment" or "in one embodiment" that may recur in various points of the present description do not necessarily refer to one and the same embodiment. Furthermore, the particular structures, peculiarities, or characteristics may be combined in any convenient way in one or more embodiments.

[0035] Same reference numerals refer to same elements or elements of similar function throughout the various figures. Furthermore, only reference numerals necessary for the description of the respective figure are shown in the figures. The shown embodiments represent only examples of how the invention can be carried out. This should not be construed as limiting the invention.

[0036] **Figure 1** is a schematic view illustrating a vehicle 1 with an electronic control unit 10 (ECU) for controlling various protection devices 2_1, 2_2, ... 2_N for occupants (not shown) in vehicle 1. Hereinafter, "left" and "right" of vehicle 1 mean "left" and "right" of the center line L in the center in the width direction of vehicle 1.

[0037] Preferably, ECU 10 is arranged centrally in vehicle 1 so as to prevent a damage to ECU 10 in the event of a possible crash. ECU 10 is communicatively connected to at least one central impact sensor 4C, which detects an impact, and at least one remote impact sensor 4R. Additionally, the at least one central impact sensor 4C and the at least one remote impact sensor 4R are preferably distributed such that it is possible to detect the location of the impact. The at least one central impact sensor 4C and the at least one remote impact sensor 4R are preferably high sensors (acceleration sensors). In the embodiment shown herein, ECU 10 is electrically connected to a left side protection device 2_1, a left front protection device 2_2, a right front protection device 2_3 and a right side protection device 2_4. Although not shown, additional protection devices 2_i, 5 <= i <= N can be provided for rear seats (not shown).

[0038] The left front protection device 2_2 and the right front protection device 2_3 may be airbags (for example, face airbags and other airbags), seat belts, seat belt pretensioners, etc., which are deployed during a frontal face collision FFC to protect an occupant in the driver seat and passenger seat. The left side protection device 2_1 and the right side protection device 2_4 may be airbags, seat belts, seat belt pretensioners, etc., which are deployed during an offset collision (not shown), a diagonal collision DC, and a side face collision SFC to protect occupants in the driver seat and passenger seat. ECU 10 controls the activity of the various protection devices 2_1, 2_2,..., 2_N. It is obvious to a person skilled in the art that protection devices 2_1, 2_2, ...2_N are also used to protect the occupants in vehicle 1 in the event of a rear face collision RFC. A coordinate system is assigned to vehicle 1. X-coordinate x is oriented along the width of vehicle 1 and Y-coordinate y is oriented along the length of vehicle 1.

[0039] **Figure 2** shows a schematic representation of a 3D sensor system 21 for determining the current position of an occupant 3 in a vehicle 1. The schematic representation shown here describes the situation in which the position of occupant 3, who is the driver of vehicle 1, is determined by at least one sensor 3D sensor system 21. It is obvious to a person skilled in the art that the present invention is not limited to determining only the position of the driver of vehicle 1. The present invention enables the position determination of all occupants 3 in a vehicle 1, and the information data obtained therefrom is used in the method for a restraint deployment strategy.

[0040] As mentioned above, the current position or size of the occupant 3 (for example driver) may be determined using at least one 3D sensor system 21. The at least one sensor 3D sensor system 21 determines the current position of occupant 3 (or occupants 3) by direct sensing. The 3D sensor system 21 may measure the depth (or distance or range) to an object based on illuminating the object with a laser (or other types of light source) and measuring the backscattered light. According to one embodiment, the 3D sensor system 21 is defined as projected-light sensors which combine the projection of a light pattern with a standard 2D camera, and depth is measured via triangulation. According to a further embodiment, the 3D sensor system 21 comprises time-of-flight sensors that measure depth by estimating the time delay between light emission and light detection.

[0041] Direct sensing of the current position of occupant 3 by the 3D sensor system 21 may be based on the use of an interior time-of-flight camera, a 3D imaging sensor, or an interior radar system.

[0042] In an embodiment, a seat sensor system 20 for at least one seat 7 of vehicle 1 comprises a plurality of sensors, which are at least one seat track sensor 12, at least one back rest sensor 13 and at least one weight sensor 14. The at least one seat track sensor 12 is assigned to a seating 9 of seat 7 and is configured to detect forward/rearward states 16 of seating 9 (seat 7) and/or to detect upward/downward states 17 of seating 9 (seat). At least one back rest sensor 13 is assigned to the back rest 8 of seat 7. It is obvious to a person skilled in the art that each seat 7 of vehicle 1 has at least one back rest sensor 13. The at least one back rest sensor 13 determines forward/rearward states 18 of the back rest 8 of the seat 7.

[0043] In addition, at least one weight sensor 14 is assigned to the seating 9 of seat 7. The at least one weight sensor 14 is configured to determine the weight of occupant 3 in the respective seat 7.

[0044] The Y-coordinate y is oriented along the length of vehicle 1, and the Z-coordinate is oriented along the height of vehicle 1.

[0045] **Figures 3A to 3C** show different schematic views, illustrating the relationship between a distance 30C of a chest 30 and a distance 31H of a head 31 of the occupant 3 from the steering wheel 5 or the dashboard 6 and the seat track (not shown) determined by the seat track sensor 12 (see Fig. 2) and/or the back rest sensor 13 (see Fig. 2). The distance 30C of chest 30 and the distance 31H of head 31 provide a high added value in case of braking situations or abrupt deceleration of vehicle 1 (see Fig. 2), where occupant 3 leans forward, while the seat track sensors 12 and/or the back rest sensors 13 do not detect this. The distance 30C of the occupant’s 3 chest 30 and/or the distance 31H of the occupant’s 3 head 31, sitting in the seat 7, are determined with the at least one 3D sensor system 21 (see Fig. 2). The 3D sensor system 21 is used to determine a current 3D head position 33 (see Fig. 4) and a current 3D chest position 36 (see Fig. 4) from a plurality of body points 32 (see Fig. 4) using a Kalman filter 40 (see Fig. 5).

[0046] **Figure 4** is a schematic representation of a plurality of 3D body points 32 on the occupant’s 3 body that are used for the calculation or determination of a current head position 33 and a current chest position 36. In order to obtain an adequate fit (adaption) of the restraint deployment, the input data for the calculation or determination are the occupant 3 size and the occupant 3 position. As shown in Fig. 4, the focus is on the exact calculation of the occupant 3 position, which is defined by the current head position 33 and the current chest position 36. The calculated current head position 33 and the calculated current chest position 36 ensure occupant safety in the vehicle 1 and are part of the adequate fit or adjustment of the restraint deployment. For the head position 33, it’s computed through the images and filtered or predicted 3D body point 32 positions (even if one or more body points 32 are occluded) by a Kalman filter. The chest position 36 is computed using the combination of the 3D body points 32 filtered or predicted (filtered or predicted right shoulder position 34F, filtered or predicted left shoulder position 35F and filtered or predicted middle spine position 37F).

[0047] The calculation of the head position 33 and the chest position 36 is based on the 3D sensor system 21 (3D imaging device), which detects body points 32 on the occupant’s 3 body surface. Each body point 32 is defined in 3D space by an X-coordinate x, a Y-coordinate y and a Z-coordinate z. The body points 32 of occupant 3 may be, for example, the head 31, the left and right shoulders, the middle spine, the hips, or the like. It should be noted for a person skilled in the art that the body points 32 shown in Fig. 4 are for descriptive purposes and should not be construed as limiting the invention. The position of the body points 32 in space is calculated frame by frame by a 3D image sensor of the 3D sensor system 21 using an image processing algorithm. These body points 32 points are used to calculate two robust pieces of information, namely the head position 33 and the chest position 36, both of which are defined by an X-coordinate x, a Y-coordinate y and a Z-coordinate z.

[0048] **Figure 5** is a schematic representation of the steps for determining the 3D head position 33 and the 3D chest position 36 of occupant 3 in vehicle 1. Using the 3D sensor system 21, a 3D position (X-coordinate x, Y-coordinate y, and Z-coordinate z) of each body point 32 and a velocity of each body point 32 (in the X-coordinate x, the Y-coordinate y and the Z-coordinate z) are determined. Consequently, the state ***st*** of each body point 32 is defined as a 6-dimensional vector (see ***st*** below).

$$\boldsymbol{st} = \begin{pmatrix} x \\ y \\ z \\ \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix}$$

[0049] The 3D head position 33 and the 3D chest position 36 are obtained after some preprocessing steps. Once the body points 32 are filtered, the head position 33 corresponds to the filtered or predicted head position 33F if the head point 33 was occluded. In a calculation section 50, a coherence check 45 is performed using the filtered head position 33F, the filtered right shoulder position 34F, the filtered left shoulder position 35F, and the filtered middle spine position 37F. The results of the coherence check 45 are transmitted to a point combination 46 to check whether the position of, for example, the 3D head point 33 is in relation to other body points 32 and takes into account the morphology of occupant 3. The output of the point combination 46 is the 3D chest position. For example, the width 38 between the body points 32 of the shoulders or the distance 39 between the head 31 and the body points 32 of shoulders is checked.

[0050] This coherence check could also be used to determine whether occupant 3 is in an out-of-range position on seat 7 (see Fig. 2) or not. For example, if occupant 3 (driver) turns backward to look towards or see the rear seats while driving, this check could be used to add a warning to alert that occupant 3 (driver) is in an out-of-range position.

[0051] After the coherence check of body points 32, the chest position 36 is determined. It corresponds to a calculation using a combination of the filtered right shoulder position 34F, the filtered left shoulder position 35F and the filtered middle spine position 37F.

$$Chest = \alpha \times ShouldLeft_{Filtered} + \beta \times ShouldRight_{Filtered} + \gamma \times SpinMid_{Filtered}$$

with: $\alpha + \beta + \gamma = 1$

[0052] The choice of the parameters α, β and γ is based on the occlusion state of the filtered right shoulder position 34F, the filtered left shoulder position 35F, and the filtered middle spine position 37F. In the ideal situation, when the filtered right shoulder position 34F, the filtered left shoulder position 35F, and the filtered middle spine position 37F are visible, the parameters are:

$$\alpha = \beta = \gamma = \frac{1}{3}$$

[0053] If any of the filtered right shoulder position 34F, the filtered left shoulder position 35F, and the filtered middle spine position 37F is occluded, for example, when a bag is placed on the occupant's lap to search for something, it may occlude the filtered middle spine position 37F for a certain period of time. As a result, γ is chosen to be smaller than the other parameters to give more importance to other visible data, thus:

$$\alpha = \beta > \gamma$$

[0054] To create a filter model, an equation of state and a measurement equation are required:

Equation of state:

[0055]

$$\boldsymbol{st^P} = \boldsymbol{Ast} + \boldsymbol{Bu} + \boldsymbol{v}$$

where $A \in R^{6x6}$, $B \in R^{3x6}$, and v is the noise.

[0056] The measurement depends on the state *st*, with some noise w, so the measurement equation is:

$$\boldsymbol{z} = \boldsymbol{Hst} + \boldsymbol{w}$$

where $\boldsymbol{z} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$ is the measurement of the 3D body position 32.

[0057] The new position can be calculated by the acceleration, speed and the last calculated position. The example shown here uses a 2D point (x and y) to show and simplify the calculation of the new body point. It is understood that the limitation to one 2D point is for descriptive purposes only and should not be construed as limiting the invention.

$$x_{new}(t) = x + \dot{x}(t) + \ddot{x}\,\frac{t^2}{2}$$

$$y_{new}(t) = y + \dot{y}(t) + \ddot{y}\frac{t^2}{2}$$

$$\dot{x}_{new}(t) = \dot{x} + \ddot{x}(t)$$

$$\dot{y}_{new}(t) = \dot{y} + \ddot{y}(t)$$

[0058] The equation of state ***st*** and ***A*** and ***B*** reads as follows:

$$\boldsymbol{xt^P} = \boldsymbol{Ast} + \boldsymbol{Bu} + \boldsymbol{v}$$

$$\boldsymbol{st^P} = \begin{pmatrix} 1 & 0 & t & 0 \\ 0 & 1 & 0 & t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \boldsymbol{st} + \begin{pmatrix} \frac{t^2}{2} & 0 \\ 0 & \frac{t^2}{2} \\ t & 0 \\ 0 & u \end{pmatrix} \boldsymbol{u} + \boldsymbol{v}$$

[0059] The measurement equation is:

$$\boldsymbol{z} = \boldsymbol{Hx} + \boldsymbol{w}$$

which results in:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \boldsymbol{H} \begin{pmatrix} x \\ y \\ \dot{x} \\ \dot{y} \end{pmatrix} + \boldsymbol{w}$$

where ***H*** is the matrix relating the measurement to the state ***st*** .

[0060] **Figure 6** is a schematic view of the filter steps used in the Kalman filter to determine the current 3D head position 33 and the current 3D chest position 36 of occupant 3 in vehicle 1.

[0061] One filter step is a predicting step 41 for predicting an estimate according to the system model. To do this, the Kalman filter 40 takes the previous parameter and error estimate and predicts the new parameters and error based on the system modeling.

[0062] A correction step 42 is carried out by comparing the predicted parameter to the measurements (3D position for each of a plurality of body points 32) by comparing the predicted position for each of a plurality of body points 31 of the occupant 3 and the determined 3D position for each of a plurality of body points 32 of the occupant 3.

[0063] An updating step 43 updates the predicted parameters with new measurements 45 of the 3D position for each of a plurality of body points 32.

[0064] Prior to the correction step 42, an eligibility test takes place to determine if the 3D position measurement (observation) and the system model are valid. The eligibility test is defined as follows:

$$\boldsymbol{Inno}^{T} \times \boldsymbol{S}^{-1} \times \boldsymbol{Inno} \leq threshold$$

with

- $\boldsymbol{Inno} = z - \hat{z}$, which is the 3D position measurement error between the raw image data 23 and the predicted observation in the Kalman filter 40. It is called innovation.
- $\boldsymbol{S}$ is the covariance of the observation error.
- $Inno^{T} \times \boldsymbol{S}^{-1} \times \boldsymbol{Inno}$ is the Mahalanobis distance.

[0065] The calculated distance is a Mahalanobis distance. The chosen threshold can ensure that the observations and the prediction are within an acceptance range. Considering Gaussian properties, this acceptance range could be an ellipsoid with center z and matrix $\boldsymbol{S}$. This threshold can also be used to distinguish or eliminate the measurement jumps due to voluntary or involuntary dynamic movements of occupant 3.

[0066] This step of eligibility test with the reliability check uses thresholds that allow the detection of errors (failures):

- If a sensor failure is detected, the step of correction 42 is performed and it is relied only on the model (update step 43 that uses only the model) only, and
- if the measurement is valid, a gain of correction is calculated, and the state prediction is estimated using this gain.

Head and Chest Calculation

[0067] Once the key body points 32 of the occupant's 3 body are filtered, the head position 33 corresponds to the head point filtered or predicted if the point was occluded. A coherence check 45 is performed using the head position 33, the shoulders and the middle spine filtered. It checks whether or not the position of one 3D point in relation to other 3D points respects the morphology of the occupant 3. For example, the shoulders width or the distance between the head and the shoulders is checked.

[0068] This coherence check could also be used to determine whether or not occupant 3 is in an out-of-range position in seat 7. For example, if the driver turns backward to see the rear seats while driving, this check could be used to add a warning to alert the driver that he is in an out-of-range position.

[0069] After the point coherence check 45, the chest position 36 is determined. It corresponds to a calculation using a combination of the filtered 3D body points of the shoulders and middle spine (Fig. 1).

[0070] **Figure 7** is a schematic view of an embodiment showing the use 3D head position 33 and the 3D chest position 36 of occupant 3 by a crash algorithm 59.

[0071] The current distance 31H of the head 31 of the distance 30C of the chest 30 of occupant 3 and other body points 32 of occupant 3 from steering wheel 5 of dashboard 3 is measured by the at least one 3D sensor system 21, which is connected to a signal acquisition and processing module 58. The 3D head position 33 and the 3D chest position 36 are used in an occupant displacement prediction module 53. The occupant displacement prediction module 53 is used to optimize the requested restraint protections based on the position of occupant 3 to ensure better coupling between the airbag or other restraint elements and occupant 3. The determined current 3D head position 33 and the determined current 3D chest position 36 of occupant 3 from the steering wheel 5 or the dashboard 6 determine the timing and efficiency of an airbag protection, which are highly dependent on its deployment time and its interaction with the head 31 or the chest 30 of occupant 3. The 3D head position 33 and the 3D chest position 36 are calculated in the signal acquisition and processing module 58 of the crash algorithm 59.

[0072] Prior to using the determined current 3D chest position 36 in the occupant displacement prediction module 53, the determined current 3D chest position 36 is sent to a fusion module 51 of the crash algorithm 59. The fusion module 51 also uses information or data from the conventional seat sensor system 20 (seat track sensor 12, back rest sensor

13, and weight sensor 14). As mentioned in the description of Fig. 2, seat track sensor 12 provides information about at least the forward/rearward states 16 of seating 9. Seat track sensor 12 can also provide upward/downward states 17 of seating 9. Back rest sensor 13 provides information about the position of the back rest 8 of seat 7. The 3D chest position 36 adds more granularities to the position of occupant 3 in seat 7. The fused occupant's 3D chest position 36, which is represented in the fused occupant classification 60, the 3D head position 33, and the results of the event detection module 52 are transmitted to the occupant displacement prediction module 53, which adjusts the deployment times of airbags and adaptive airbags, allowing a tailored deployment of the restraints according to the detection of a crash.

[0073] The fused occupant classification 60 and a result 62 from the occupant displacement prediction module 53 are fed to the deployment requests module 54, allowing an adjustment of the restraint system strategy in function of the occupant classification.

[0074] It is believed that the present disclosure and many of its attendant advantages will be understood by the foregoing description, and it will be apparent that various changes may be made in the form, construction, number and arrangement of the components without departing from the disclosed subject matter or without sacrificing all of its material advantages. The form described is merely explanatory, and it is the intention of the following claims to encompass and include such changes. Accordingly, the scope of the invention should be limited only by the claims appended hereto.

LIST OF REFERENCE NUMERALS

[0075]

1	Vehicle
$2_1, 2_2, ...2_N$	Protection devices
3	Occupant
4C	Central impact sensor
4R	Remote impact sensor
5	Steering wheel
6	Dashboard
7	Seat
8	Back rest
9	Seating
10	Electronic control unit (ECU)
12	Seat track sensor
13	Back rest sensor
14	Weight sensor
16	Forward/rearward state
17	Upward/downward state
18	Forward/rearward state
20	Seat sensor system
21	3D sensor system
23	Raw image data
30	Chest
30C	Distance of chest
31	Head
31H	Distance of head
32	Body point
33	Head position
33F	Filtered head point
34F	Filtered right shoulder position
35F	Filtered left shoulder position
36	Chest position
37F	Filtered middle spine position
38	Width
39	Distance
40	Kalman filter
41	Predicting
42	Correcting
43	Updating
45	Coherence check

46	Point combination
50	Calculation section
51	Fusion module
52	Event detection module
53	Occupant displacement prediction module
54	Deployment requests module
58	Signal acquisition and processing module
59	Crash algorithm
60	Fused occupant classification
62	Result
L	Center line
st	State
x	X-coordinate, x-direction
y	Y-coordinate, y-direction
z	Z-coordinate, z-direction

Claims

1. A method for determining positions of an occupant (3) in a vehicle (1) to adapt a restraint deployment of the vehicle (1), the method comprising:

providing at least one 3D sensor system (21) for capturing a plurality of time-delayed image frames of the at least one occupant (3) in the vehicle (1);
determining a 3D position for each of a plurality of body points (32) of the occupant (21) from raw image data (23) per captured image frame;
transmitting the 3D positions of the plurality of body points (32) to a Kalman filter (40) to determine a filtered or predicted head position (33F), a filtered or predicted right shoulder position (34F), a filtered or predicted left shoulder position (35F), and a filtered or predicted middle spine position (37F) from the plurality of body points (32);
inputting the filtered or predicted head position (33F), the filtered or predicted right shoulder position (34F), the filtered or predicted left shoulder position (35F), and the filtered or predicted middle spine position (37F) to a calculation section (50) which calculates a current 3D head position (33) and a current 3D chest position (36); and
using the current 3D head position (33) and the current 3D chest position (36) as an input for determining the position of the occupant (3) in the vehicle (1) and an adaption of the restraint deployment of the vehicle (1).

2. The method according to claim 1, wherein a signal processing module (58) is applied to calculate a state (st) for each image frame of the plurality of body points (32) of the occupant (3), wherein each body point (32) is defined by its position in an x-direction (X), a y-direction (Y) and a z-direction (Z) and its corresponding speed (i) in the x-direction (X), (y) in the y-direction (Y) and (z) in the z-direction (Z).

3. The method according to any of the preceding claims, wherein the Kalman filter (40) comprises the steps of:

- predicting (41) a state (***st***) of a 3D position for each of a plurality of body points (32) of the occupant (3) by taking the previous 3D position for each of a plurality of body points (32) of the occupant and an error estimate;
- correcting (42) by comparing the predicted position for each of a plurality of body points (32) of the occupant (3) and the measured 3D position for each of a plurality of body points (32) of the occupant (3); and
- updating (43) the 3D position for each of a plurality of body points (32) of the occupant (3) for one image frame with the measured 3D position of a plurality of body points (32) of the occupant (3).

4. The method according to claim 3, wherein the predicting (41) predicts the state state (***st***) according to the system model for the next iteration.

5. The method according to claim 3, wherein prior to the correcting (42), an eligibility test is carried out to determine whether or not the measured 3D position and the model are valid, wherein the eligibility test is based on the Mahalanobis distance:

$$Inno^T \times S^{-1} \times Inno \leq threshold.$$

6. The method according to claim 5, wherein ***Inno*** = $z - \hat{z}$ which is a measurement error between the raw image data (23) and the predicted 3D positions of the body points (32).

7. The method according to claim 5, wherein the eligibility test combines the Mahalanobis distance with an estimation of the measurement quality.

8. The method according to claim 1, wherein a coherence check (45) is carried out on the filtered head position (33F), the filtered right shoulder position (34F), the filtered left shoulder position (35F), and the filtered middle spine position (37F) to determine the 3D head position (33).

9. The method according to claim 8, wherein a result of the coherence check (45) is sent to a point combination (46) to determine the 3D chest position (36).

10. A non-transitory computer-readable medium storing program instructions executable on an electronic control unit (10) of a vehicle (1) to perform a computer-implemented method for determining a 3D head position (33) and a 3D chest position (36) of an occupant (3) in a vehicle according to the preceding claims.

11. A system for determining positions of an occupant (3) used in a restraint deployment adaption in a vehicle (1), comprising:

an electronic control unit (10) of the vehicle (1);
a fusion module (51), an event detection module (52), an occupant displacement prediction module (53), and a deployment requests module (54) being part of the electronic control system (10);
at least one 3D sensor system (21) adapted to capture a plurality of time-delayed image frames of the at least one occupant (3) in the vehicle (1), the at least one 3D sensor system (21) being connected to a signal acquisition and processing module (58) of a crash algorithm (59);
characterized by
a Kalman filter (40) in the signal processing module (58) that determines a filtered head position (33F), a filtered right shoulder position (34F), a filtered left shoulder position (35F), and a filtered middle spine position (37F) from a plurality of body points (32) captured by the at least one 3D sensor system (21); and
a calculation section (50) that calculates a current 3D head position (33) and a current 3D chest position (36) from the filtered head position (33F), the filtered right shoulder position (34F), the filtered left shoulder position (35F), and the filtered middle spine position (37F) for use in the crash algorithm (59).

12. The system according to claim 11, wherein the signal processing module (58) is applied to calculate a state (st) for each image frame of the plurality of body points (32) of the occupant (3), each body point (32) being defined by its position in an x-direction (X), a y-direction (Y), and a z-direction (Z) and its corresponding speed (i) in the x-direction (X), (y) in the y-direction (Y) and (z) in the z-direction (Z).

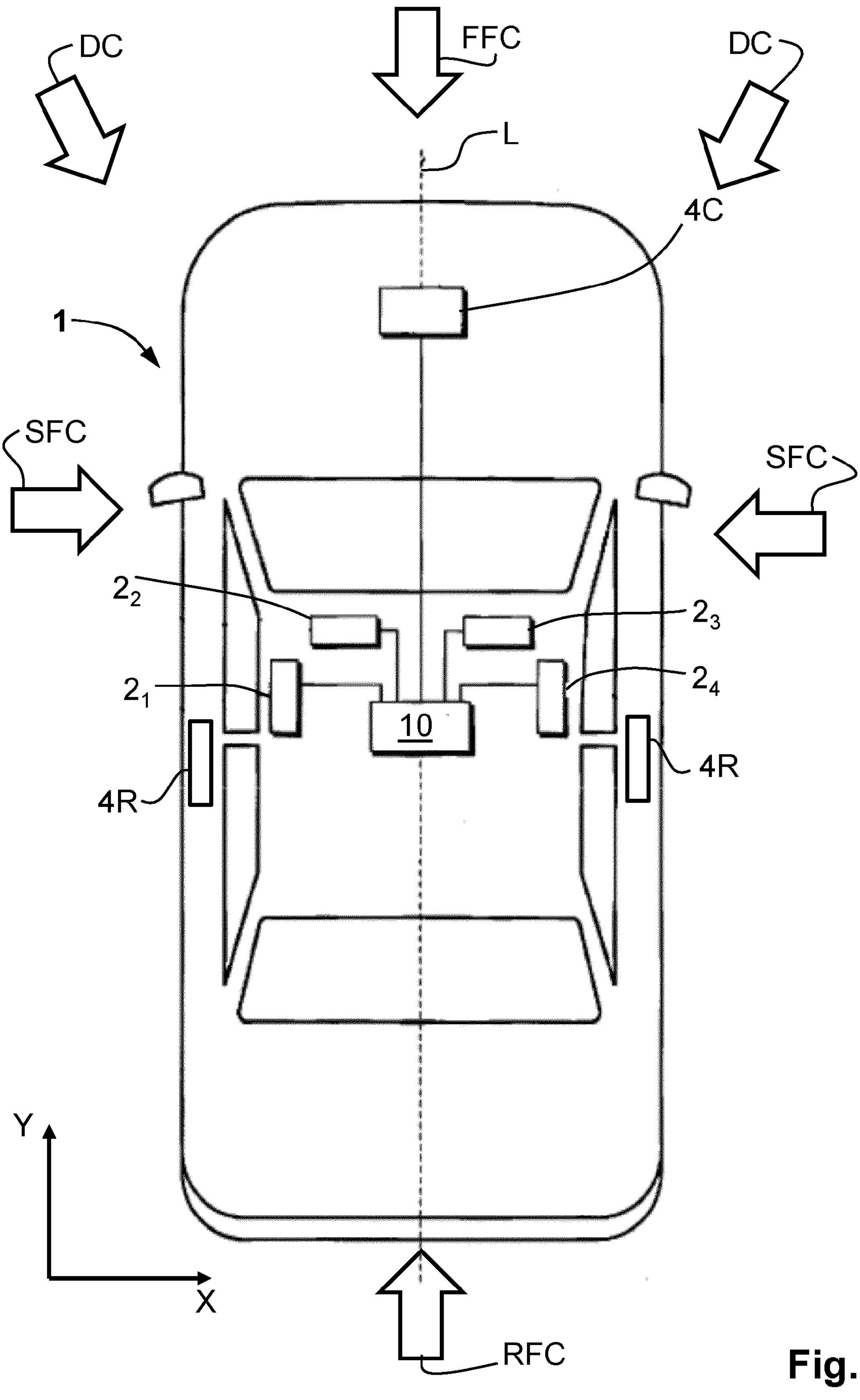

Fig. 1

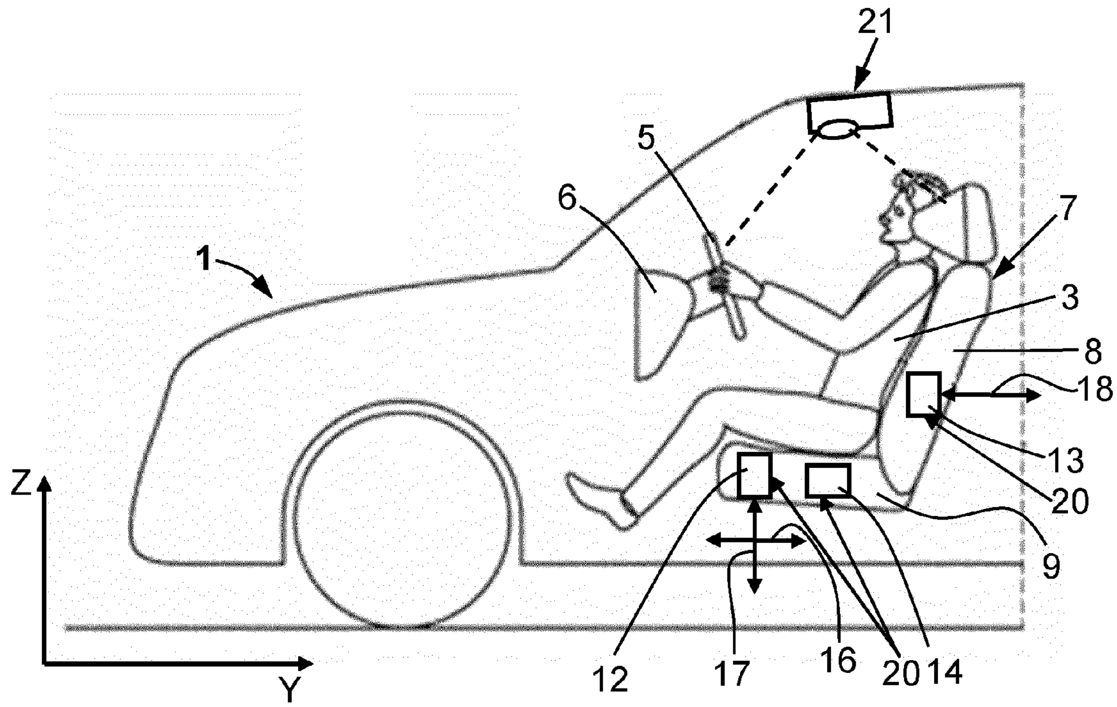

Fig. 2

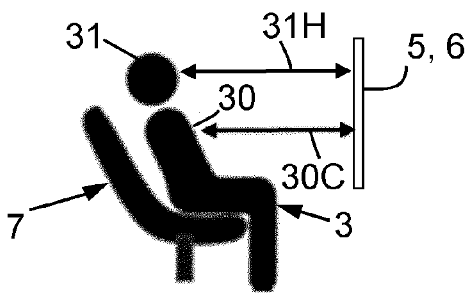

Fig. 3A

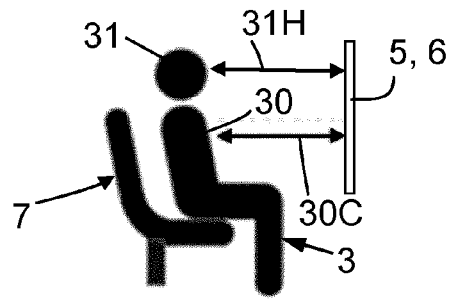

Fig. 3B

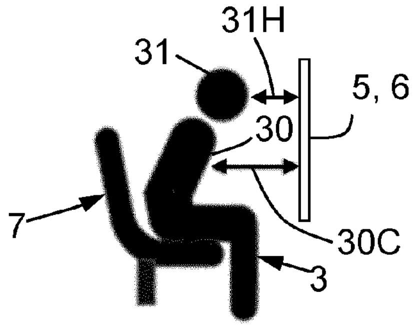

Fig. 3C

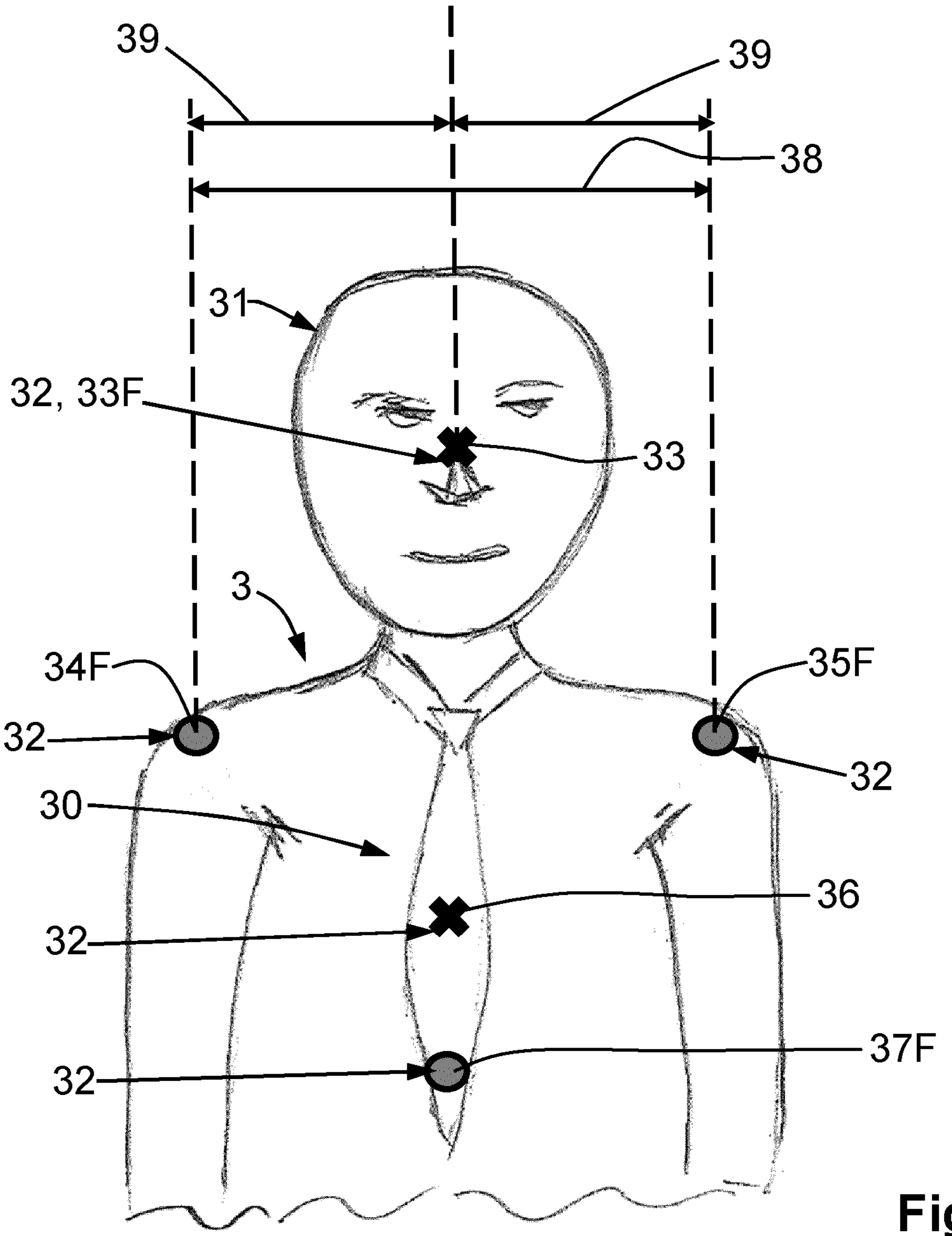

Fig. 4

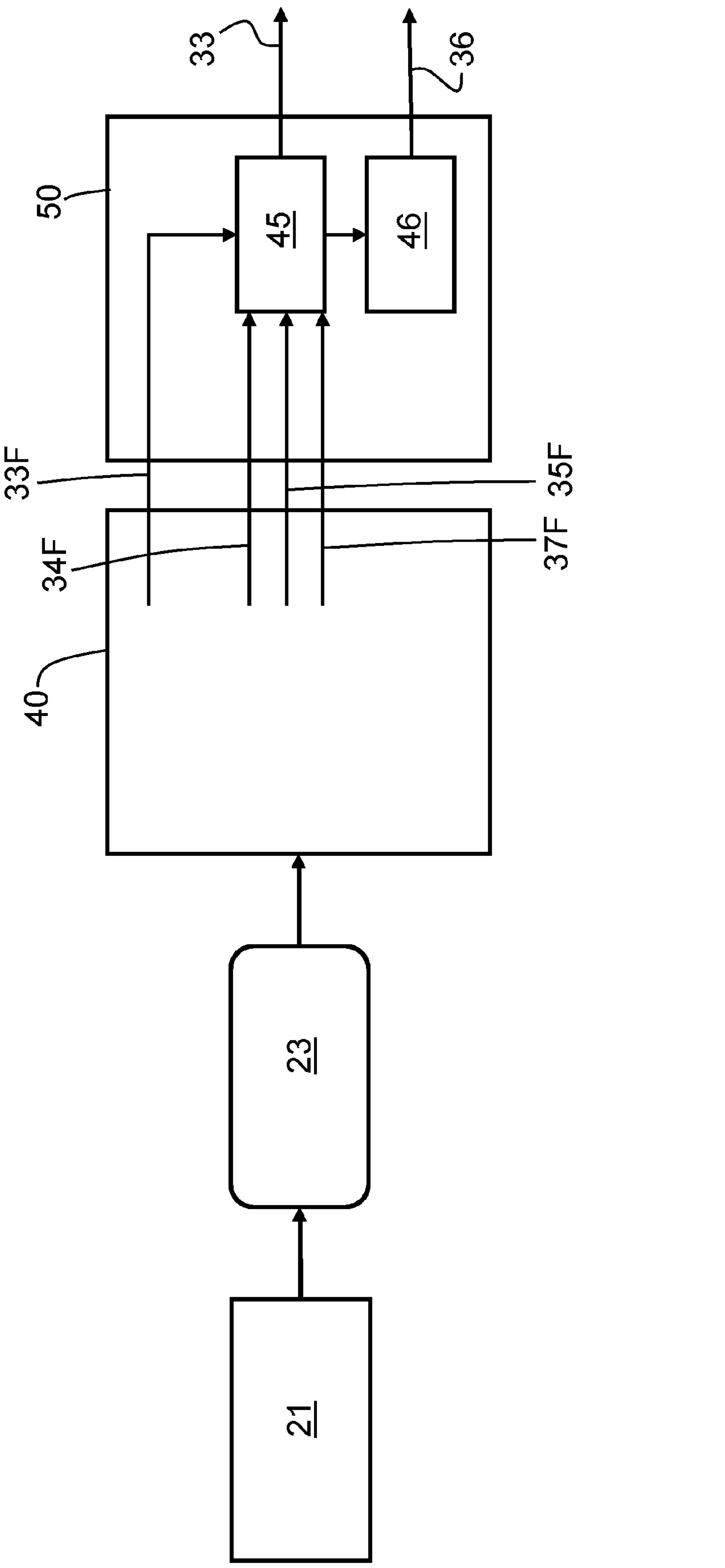

Fig. 5

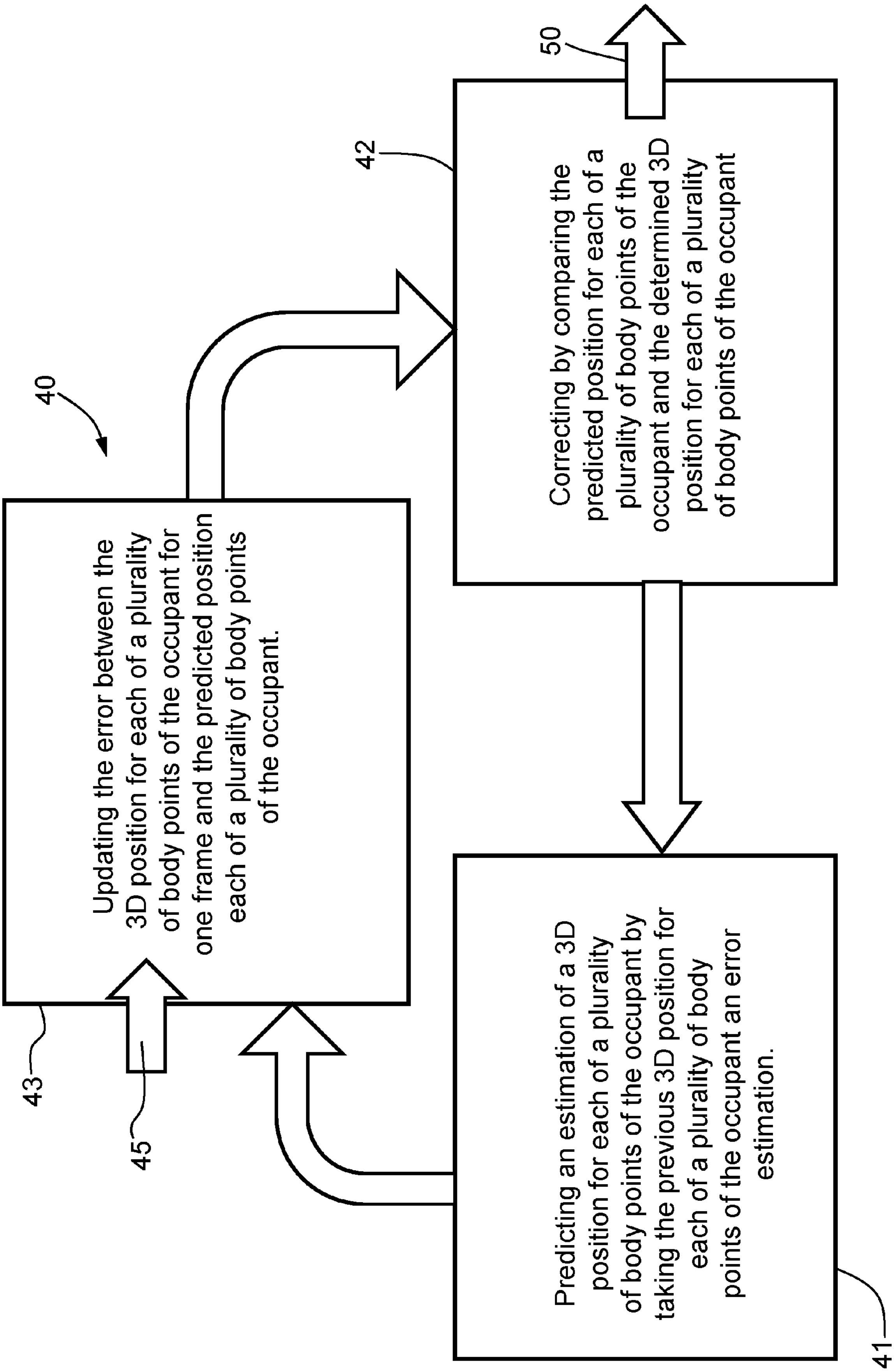
40
41
Predicting an estimation of a 3D position for each of a plurality of body points of the occupant by taking the previous 3D position for each of a plurality of body points of the occupant an error estimation.
42
Correcting by comparing the predicted position for each of a plurality of body points of the occupant and the determined 3D position for each of a plurality of body points of the occupant
43
Updating the error between the 3D position for each of a plurality of body points of the occupant for one frame and the predicted position each of a plurality of body points of the occupant.
45
50

Fig. 6

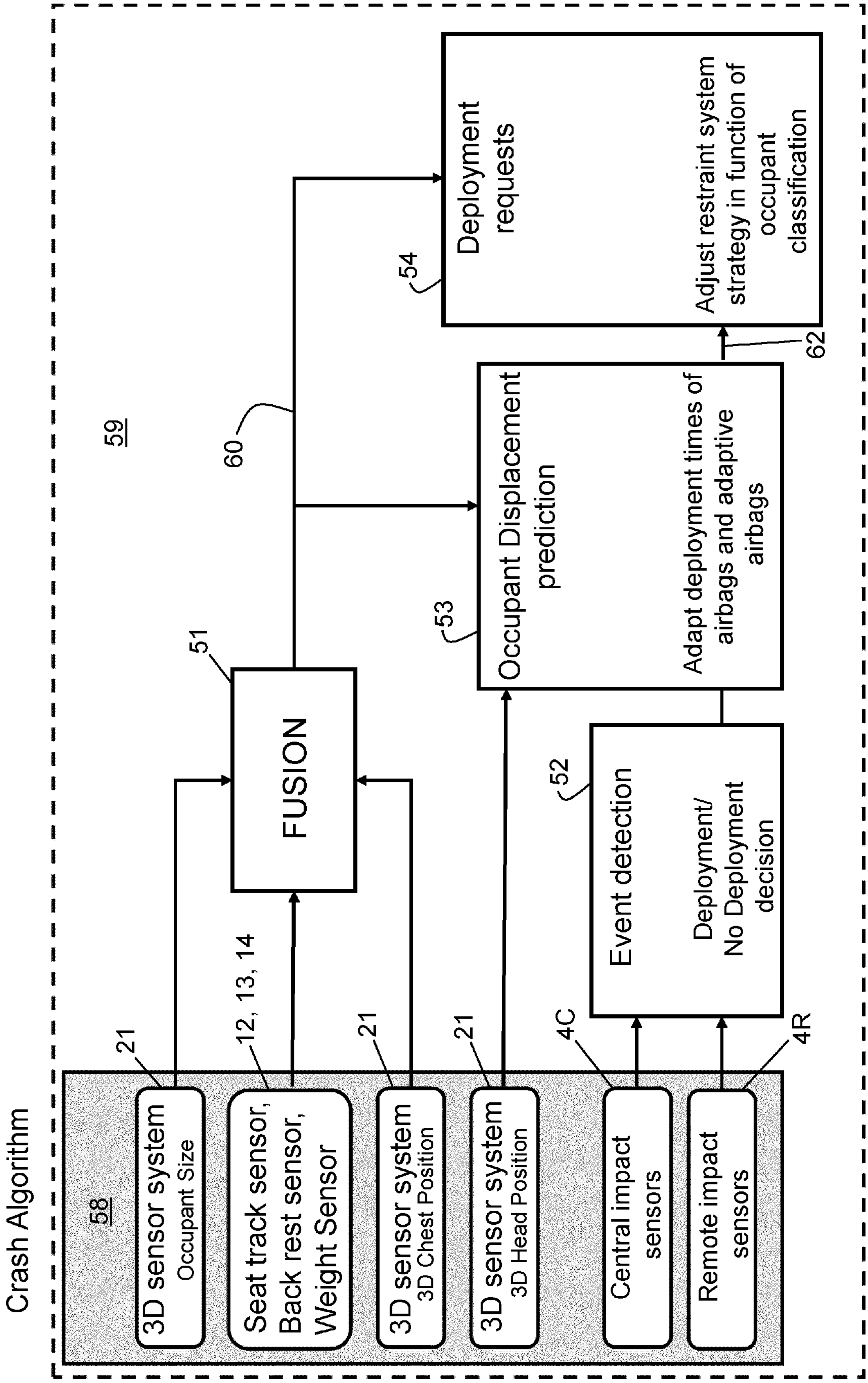
Crash Algorithm
58
3D sensor system
Occupant Size
Seat track sensor,
Back rest sensor,
Weight Sensor
3D sensor system
3D Chest Position
3D sensor system
3D Head Position
Central impact
sensors
Remote impact
sensors
21
12, 13, 14
21
21
4C
4R
FUSION
51
Event detection
Deployment/
No Deployment
decision
52
Occupant Displacement
prediction
Adapt deployment times of
airbags and adaptive
airbags
53
60
59
Deployment
requests
Adjust restraint system
strategy in function of
occupant
classification
54
62

Fig. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 23 15 8682

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B60R
G06T

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Berlin	13 July 2023	Kyriakides, Leonidas

2

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13-07-2023

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